The odyssey of managing feral camels and their impacts—is there an Achilles' heel?

Jocelyn Coventry[1], Glenn Edwards[2] and Benxiang Zeng[2]

[1] Department of Resources, PO Box 8760, Alice Springs NT 0871

[2] Department of Natural Resources, Environment, The Arts and Sport, PO Box 1120, Alice Springs NT 0871

ABSTRACT

Australia supports the largest population of free-ranging, one-humped camels *Camelus dromedarius* in the world. These feral camels originated and bred from camels introduced into Australia up to 160 years ago. With estimated doubling of numbers every eight years, it is believed that in 2007 there may have been over one million feral camels. This has been associated with increasing negative impacts on desert ecology, cultural values and human enterprise.

In this paper, the potential to exploit Achilles' heel aspects of camels has been examined; this has helped identify opportunities to either improve or develop methods for broad-scale management of feral camels and their impacts in Australia. This has also highlighted the importance of considering aspects of camel–specific behaviour for the planning and implementation of feral camel management.

Conventional assessment according to 'ideal' criteria indicates that there are satisfactory levels of humaneness and cost-effectiveness in some or all situations where methods are currently used for broad-scale management of feral camels and their impacts.

Based on the current potential to meet 'ideal' criteria, as well as a future potential for improvement or development, recommendations have been made for continued use of the following currently-used management methods: aerial and ground surveys; destructive aerial and ground culls; on-site 'pet-meat' slaughter; trapping; and mustering. The three currently-used methods of exclusion fencing are not recommended for broad-scale management of feral camels and their impacts; their application is only suitable for protection of localised areas of high value. Five currently-unused, but impending management methods (satellite remote sensing, habitat modelling, 'Judas' animal technique, on-site 'game-meat' slaughter, on-site abattoir slaughter) are recommended for development and use. Another two currently-unused management methods have been considered to have sufficient potential to warrant further investigation—attractant and humane biocide.

Opportunities have been identified where complementary use of management methods could improve or develop currently-used methods—in particular through use of satellite remote sensing, habitat modelling, attractants or the 'Judas' animal technique. These could enhance the predicting, locating and concentrating of feral camel numbers for survey methods and destock approaches. Improvement and integration of destocking activities would facilitate development of on-site abattoir and 'game-meat' slaughter operations.

Key words: feral camel, Australia, Achilles' heel, vertebrate pest control, complementary management

Introduction

Camels *Camelus dromedarius* were first introduced into Australia in the 1840s for transport and haulage to enable recent settlers to explore and develop the arid interior of South Australia (SA) and the Northern Territory (NT), and later develop the north-west pastoral areas and goldfields of Western Australia (WA). After the introduction of rail and motorised transport in the 1920s, many camels were released, abandoned or escaped domestication to survive in the immediate arid areas. A NT population survey conducted in 2001 suggested that there was a minimum of 300,000 feral camels in Australia (Edwards *et al.* 2004) and the population was doubling every eight years. In 2008 the actual population size may have exceeded one million (Saalfeld and Edwards 2008).

Adaptations to arid conditions, an absence of natural predators (Grigg 2007) and an absence of serious endemic disease (Brown 2004) have enabled feral camels to thrive on the arid rangelands of Australia.

Emerging Problems

Feral camels have assumed a pest status in Australia (McCloy and Rowe 2000; Department of the Environment and Heritage 2004; Grigg 2007) and are now widely distributed across arid regions (Figure 1), including the Simpson, Tanami, Great Victoria, Gibson and Great Sandy deserts. At current densities, feral camels are having measurable negative impacts on a range of values in these arid regions.

Theme edition of Australian Zoologist "*Ecology meets Physiology*", a Gordon Grigg festschrift, edited by Lyn Beard, Daniel Lunney, Hamish McCallum and Craig Franklin. Australian Zoologist Vol 35 (2) 2010.

A NT paddock-based study with a stocking rate of 1 to 4 camels per km^2 showed overgrazing on highly palatable flora—Wild Potato *Ipomoea costata*, Curly-pod Wattle *Acacia sessiliceps*, Bean Tree *Erythrina vespertilio, Quandong Santalum acuminatum* and Plum Bush *S. lanceolatum* (Dörges and Heucke 2003; Dörges *et al.* 2003a). During the 2001 NT survey, the overall estimate of feral camel density was 0.35 camels per km^2; some localised densities were in excess of 4 camels per km^2 (Edwards *et al.* 2004), which was a higher density than the NT paddock-based study. Shortly after, a survey in South Australia noted signs of damage by feral camels to other native flora—Desert *Kurrajong Brachychiton gregorii*, Desert Poplar *Codonocarpus cotinifolius*, Native Pine *Callitris glaucophylla*, Cassia *Senna* sp. and Twinleaf *Zygophyllum* sp. (Peeters *et al.* 2005). It was therefore noted that impacts of high feral camel densities on native flora would require further study.

A more recent aerial survey of feral camel density has estimated 0.84 camels per km^2 in WA (Ngaanyatjarra Lands) and 0.65 camels per km^2 in SA (Anangu Pitjantjatjara Yankunytjatjara (APY) Lands). This survey was undertaken between May and June 2007 in an area of 128,000 km^2 that straddles the northern WA-SA border (Lethbridge and Gee 2007). This area is believed to have one of the highest densities of feral camels in Australia.

Ground surveys in some areas habitually frequented by feral camels have indicated fouling of natural waters (Government of South Australia 2003; Edwards *et al.* 2004; Agriculture Western Australia 2005), plus trampling and destabilisation of sand dunes and salt lakes (Edwards *et al.* 2004). Adverse ecological impacts on soil and vegetation by large feral herbivores have been previously recorded with respect to feral horses in Australia (Dobbie *et al.* 1993) and the United States (Smith 1986). Similarly with feral camels, there is concern that their ground impacts may adversely influence the habitat and diet availability for native fauna (Peeters *et al.* 2005).

Feral camel impacts are already translating into degradation of culturally significant areas. At Uluṟu-Kata Tjuṯa National Park, NT, traditional owners and National Park Rangers have had to install cable fencing to exclude camels from significant waterholes (Bertram *et al.* 2007). In other areas of central Australia, the Greening Australia - Water for Life Program has been instrumental for management of waterholes (Greening Australia 2005), particularly with respect to construction of fences to exclude camels and reduce the degradation that they cause (Barker and Rich 2007).

The encroachment of feral camels onto pastoral properties and remote settlements is becoming increasingly common, and has been associated with damage to infrastructure such as fences, stock yards, windmills and houses. In January 2007, feral camels were reported by populist media to be rampaging through a Western Desert Aboriginal community (New Scientist Environment and Reuters 2007).

Critical Issues

Multifarious management approaches are required to curb the threats that feral camels pose to desert ecology, cultural values and human enterprise (Edwards *et al.* 2004; Peeters *et al.* 2005); however, there are some big challenges. There are large numbers of feral camels that roam widely over a range of different land tenures—mostly in remote locations (aboriginal freehold and leasehold, pastoral leases, conservation reserves, vacant crown land). As a result, mitigation of feral camel impacts will require a large financial outlay for logistical operations and a large time investment to consult with the many stakeholders regarding their perceptions and values. Some perceive feral camels less as a pest and more as a potential resource for tourism ventures, live export, control of 'woody weeds' on pastoral properties, or production of camel meat, milk, wool, leather and fat (Brian 2005; Grigg 2007; Edwards 2008a).

Current Management and Research

Management activities to date have not arrested the population growth or greatly mitigated the negative impacts of feral camels. This indicates a need to escalate or augment management activities. Current management is polarised between fencing-off culturally-sensitive areas (waterholes) and reduction in the numbers of feral camels. The latter has been undertaken with reactive, destructive culls (aerial and ground) as well as with commercial harvesting. Camels have been mustered and transported off-site over long distances (overseas, interstate) for export or slaughter at abattoirs; camels have also been slaughtered and processed on-site in 'pet-meat' slaughter operations (Zeng and McGregor 2008).

Feral camels are highly mobile (Edwards *et al.* 2001; Edwards *et al.* 2004) and distributed across four states and territories of Australia, so a cross-jurisdictional approach is needed to manage the species and its impacts. The first attempt to foster cross-jurisdictional ('nation-wide') management was a workshop held in Alice Springs in April 2005 (Edwards 2008a). This was funded by the Bureau of Resource Sciences (National Feral Animal Control Programme) and the NT Government. Soon after, the Desert Knowledge Co-operative Research Centre (DKCRC) obtained funds through the Natural Heritage Trust for the project: 'Cross-jurisdictional management of feral camels to protect NRM and cultural values' to develop a nationwide management framework. This DKCRC project examined stakeholder perceptions about feral camels, collated data on the impacts of feral camels, examined the options for managing feral camels and their impacts, and defined the legislation governing the management of feral camels (Edwards 2008b). The management framework developed under this project recommended an integrated approach that focussed on mitigating the negative impacts of feral camels rather than on reducing the numbers of feral camels *per se* (Edwards *et al.* 2008). The focus on impacts is consistent with the Australian Pest Animal Strategy (2007). That said, it is recognised that the level of damage caused by vertebrate pests is positively correlated with population

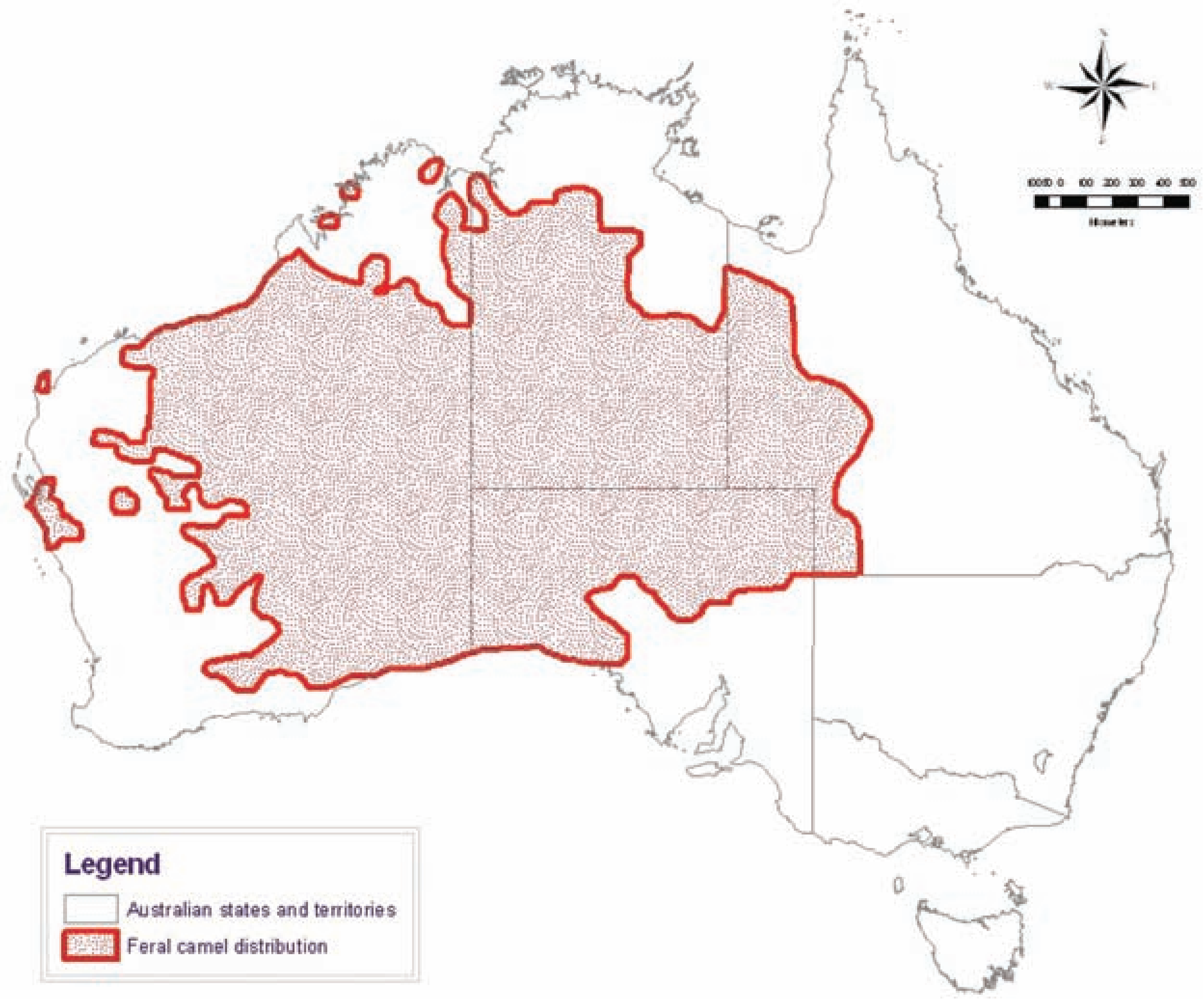


Figure 1. Feral camel distribution in Australia (Saalfeld and Edwards 2008)

density so reduction in numbers is often fundamental for management of negative impacts (Hone 2007). An integrated management approach has been described in Australia for programs to manage feral goats, feral horses and feral pigs (Dobbie *et al.* 1993; Choquenot *et al.* 1996; Parkes *et al.* 1996). Management approaches and methods used should meet the criteria for an 'ideal' vertebrate pest control method, i.e. effective, easy to use, safe for human operators and contacts, affordable, humane, target species-specific and environmentally safe (McLeod *et al.* 2007, as per Littin *et al.* 2004). The DKCRC project also recommended that the management approach or methods used in a particular situation should be contextually appropriate (Edwards *et al.* 2008). It is already understood that some management activities are not appropriate on Aboriginal lands (Vaarzon-Morel 2008).

Is There an Achilles' Heel?

The quest to improve management of feral camels and their impacts leads us to the question: "Do camels have an Achilles' heel that could be exploited?"

The 'Achilles' heel' principle is a recognised paradigm of vertebrate pest management—it considers unique or divergent aspects of a species' physiology, behaviour, morphology or biochemistry (Lindeman and Orchard 2004 as per Marks 2001) that could be exploited to either improve existing management methods or develop a new management method (technique). Ideally, improved or developed methods would be more humane, more target-specific and more effective than those currently used. An additional benefit of considering a potential Achilles' heel is that it often encourages a multi-disciplinary approach (Lindeman and Orchard 2004, as per Marks 2001) that helps identify the opportunities for improving or developing management methods.

Within the following three subsections, Achilles' heel aspects (health risks, camel-specific physiology, anatomy and behaviour) are considered from the perspective of their exploitation to improve current methods or to develop potential methods for managing feral camels and their impacts.

Considerations for an Achilles' Heel

1. Health risks—vulnerability to pathogens, toxins and deficiencies

A range of fatal risk factors has been reported in domestic or feral camels, overseas and in Australia. In overseas countries, the highest level of mortality in camels has commonly been reported in camels under six months of age (10% to 56% of age-group) (Agab 2006; Sena *et al.* 2006). In mature camels, diagnosed causes of mortality have included infections, infestations and feed-related poisonings or deficiencies (Manefield and Tinson 1997).

Bacterial, viral and parasitic risks

Clostridial disease in camels may be related exclusively to intensive husbandry (enterotoxaemia) and may also be associated with extensive management (anthrax, botulism) (Bergin and Torenbeeck 1991; Radostits *et al.* 2007).

Potentially fatal microbial diseases such as melioidosis (Bergin and Torenbeeck 1991) and aspergillosis (el-Khouly *et al.* 1992) have been related to introduction of camels into new areas of Australia and overseas countries. In Africa and the Middle East, reports of camel disease are increasingly being related to climate change and an expanding geographic range of camels (Koenig 2007) that brings them into contact with insect vectors of disease. In addition, husbandry of camels in larger herds and smaller spaces for meat, milk and racing (Koenig 2007) is exacerbating the risk of stress-related immune depression and disease spread.

Potentially fatal parasitic diseases of camels (trypanosomiasis, tick paralysis) (Musca and Osman 1990; Manefield and Tinson 1997; Agab 2006) and potentially fatal viral diseases of camels (camel pox, parapox (contagious ecthyma), Rift Valley fever) (Jezek *et al.* 1983; Gitao 1994; Pfeffer *et al.* 1998; ProMED 2006; Bardsley 2007) have been extensively reported in Africa (Sudan, Ethiopia, Eritrea, Somalia, Kenya) and the Arabian Gulf (United Arab Emirates, Saudi Arabia), but are still exotic to Australian camels. A survey on a Saudi Arabian camel dairy farm indicated that more than 50% of deaths were attributed to trypanosomiasis, with diazinon poisoning being the second most common cause of death (15% of causes) (Agab 2006).

In general, camels in Australia suffer little pathogenic disease—skin disease as a result of sarcoptic mange or corynebacteria abscesses (Brown 2004) is the most frequent cause of feral camel morbidity. This is in contrast to overseas countries where skin disease (camel pox) is a serious cause of camel morbidity and mortality if vaccine is unavailable or ineffective (Koenig 2007). Camel pox is actually one of the few causal agents of fatal camel disease that appears to be camel–specific.

Feed-related risks

Compared to other animal species, camels are less frequently reported to be poisoned by plants; this is attributed to their capacity to eat a varied diet and active ruminal contractions that thoroughly mix their fore-stomach ingesta (Manefield and Tinson 1997). Reported plant poisonings have involved four plant species of arid or northern Australia—Desert Poison Bush *Gastrolobium grandiflorum*, Camel Poison/ Sandhill Corkbark *Gyrostemon ramulosus*, Emu Poison Bush *Duboisia hopwoodii* and Poison Peach *Trema tormentosa*. General feed-related poisonings have been associated with high-nitrogen plants (Koenig 2007), aflatoxin in stored feed (Osman *et al.* 2004), urea in intensive agriculture (Agab 2006) and salinomycin in intensive animal husbandry (Koenig 2007). Camel fatalities involving heart failure and aortic rupture have been associated with deficiencies in vitamin E and selenium nutrition (Manefield and Tinson 1997).

Other risks

Some causes of mass camel mortality have not been diagnosed with the benefit of a veterinary disease investigation. In African and Arabian Gulf countries over the past twelve years (1995 to 2007), mass camel mortality has been associated with a 'camel respiratory disease' (ProMED 2006) and 'peste des petit ruminants' (PPR) virus (Koenig 2007; Scenta 2007). More recently, an unknown phytotoxin, mycotoxin or mineral deficiency has been implicated in mass mortality (Bardsley 2007; Koenig 2007; Scenta 2007). Even in Australia, undiagnosed mass camel mortality has been reported (Gee 2007, pers. com.).

The above reports of camel disease associated with either movement to new areas or unknown pathogenic factors highlight the potential for mortality risks to increase with a combination of unique environmental factors and particular camel pathogens. This also highlights the potential for relevant information to be disclosed in overseas findings. That said, it appears that biological disease agents have poor potential for broad-scale management of feral camels or their impacts in Australia (Lapidge *et al.* 2008). Prohibitive hurdles will include objections based on pathogens of poor camel-specificity, as well as issues of animal welfare, marketing and national biosecurity. All summarised biological disease agents are either non-specific or exotic to Australia; considering the relative disease free-status of Australia's camel population (Brown 2004), authorisation to release a novel infectious agent into the feral camel population is unlikely. In contrast, toxins that have caused camel mortality may have potential as humane biocides for feral camels.

Vulnerability to a biocide

Functional kidney, circulation and skin are essential for camels to survive heat and dehydration in a desert environment, and thus may either be strategic targets for a humane biocide, or their central role in homeostasis and maintenance of vascular function may translate into increased vulnerability to toxins that target the kidney and the cardiovascular system. Physiological and anatomical features of the camel kidney, circulation, skin and coat contribute to body water conservation and thermoregulation; high renal filtration produces urine of low volume with high concentration and salinity (Schmidt-Nielsen 1964; Maloiy 1972), enabling return of over 99% of renal filtrate to the circulation. During periods of dehydration, body water, plasma fluid volume and blood flow are maintained (Manefield *et al.* 1997) with the assistance of the osmotic nature of plasma proteins (Schmidt-Nielsen 1964; Maloiy 1972), hydrophilic haemoglobin (Bogner *et al.* 1998) and stable, ellipsoid-shaped erythrocytes (Smith *et al.* 1979; Schroter *et al.* 1990). The camel coat also helps conserve body water with effective insulation and efficient perspiration (Schmidt-Nielsen 1964, 1990).

Humane biocide

The nature of ingested plant and feed-related toxins that have caused camel mortality provides insight into the toxic principles that could be successful in a humane biocide for feral camels. Some toxins like salinomycin (amino-glycoside antibiotic) and trematoxin (plant toxin) can have a primary cytotoxic effect (nephrotoxicity, hepatotoxicity); some toxins have primary neuromuscular effects (e.g. atropine alkaloids) and others have primary cardiovascular effects (e.g. urea, sodium monofluoroacetate (1080), hydrocyanic acid, nitrates) (Clarke and Clarke 1975; Booth and McDonald 1982). On account of potentially higher mortality with a cardiovascular toxin and higher vulnerability of camels to toxins that target the cardiovascular system, the use of biocides with primary cardiovascular effects should be preferentially investigated for management of feral camel populations. To this end, investigation of nitrite salts has been suggested (Lapidge *et al*. 2008).

Selection and development of a suitable biocide would need to be undertaken in consultation with APVMA (Australian Pesticides and Veterinary Medicines Authority n.d.)—the authority that registers the use of pesticides in Australia. The registration process may need to address concerns about the non-target effects of chemicals that previously have been used at low levels as livestock feed additives, but now may be used at high (toxic) levels as a humane biocide. For example, the use of amino-glycoside antibiotics would create concern about development of antibiotic-resistant bacteria in the food-chain, and the use of urea would create concern about the risk to cattle on pastoral leases. In contrast, use of 1080 would pose no challenge to good principles of livestock therapy and nutrition. This is simply a toxin that is lethal to camels in a natural form (plant poisoning), as well as a biocide that is currently used for vertebrate pest control.

This leads us to overarching animal welfare issues regarding pain avoidance, alleviation and perception with respect to selection of a suitable biocide.

Animal welfare issues

With respect to pain associated with specific methods (techniques) of current vertebrate pest control, major animal welfare groups (Royal Society for Prevention of Cruelty to Animals (RSPCA), Australian and New Zealand Federation of Animal Societies (ANZFAS)) have accepted the need to use currently available methods (Braysher 1993), along with a commitment to ongoing review of specific techniques' humaneness. This acceptance is partly based on the lesser adverse outcome(s) if suffering is avoided in a future number of animals (Oogjes 1997), and partly based on selection of activities with the best consequences under the given practical constraints (Singer 1997).

With respect to pain alleviation, pain perception and use of a biocide, the debate over the use of 1080 provides a good case study. Firstly, there has been a lack of agreement on how to objectively assess pain—principally because of the range of strategies used by different animal species to demonstrate pain sensation, and also because of the difficulty in assigning relative levels of pain (Barnett and Jongman 1996). Where 1080 is used for feral rabbit and feral pig control, it produces a fatal toxicity of disputed humaneness (Marks 1996). In herbivores it is understood that 1080 affects the cardiac system and the animals appear to die peacefully. In carnivores the central nervous system appears to be affected—the subsequent convulsions are associated with apparent distress (Gregory 1996; Oogjes 1996, as per NCCAW 1992), but they are similar to the convulsions of human hyperinsulinism and epilepsy, and thus suggest the absence of pain (Marks 1996). In recognition of views to the contrary, analgesics such as narcotics (Marks 1996) and tranquillisers (Lindeman and Orchard 2004, as per Marks *et al.* 2000) have been examined as a means to alleviate apparent suffering prior to death by 1080 poisoning. Use of tranquillisers (oral diazepam) for wildlife management has been demonstrated in wild deer in defined locations (Done *et al.* 1975), but not without deaths in targeted deer (Thomas *et al.* 1967) and adverse effects in non-target species (horses) (Huntington *et al.* 1993). As for anaesthetics, use of analgesics has limitations in terms of expense, restricted access, short-term effects, safety, residues and potential of misuse. On this account, use of analgesics to assist with broad-scale management of feral camel populations would have poor feasibility.

Based on the lethal toxins summarised in this subsection, there is indication of what may be a suitable type of biocide to manage feral camels or their impacts, pending resolution of animal welfare issues and development of a camel-specific delivery technique to circumvent non-target effects. A delivery technique could be a 'bait' tailored to specific features of camel feeding behaviour and anatomy—in a salt lick or a form that is accessible by high browsing *as per* Lapidge et *al.* (2008). As explained in the next subsection, salt may be an attractant for feral camels when other natural sources are scarce. Alternatively with their long necks, adult camels would be able to reach up high to browse.

2. Attraction to basic dietary components—water, feed and salt

Water, feed and supplementary salt are basic dietary needs for camels. Scarce sources of these dietary needs are actively sought out by feral camels over geographic ranges in excess of 4,900 km^2 (Edwards *et al.* 2001). Under particular conditions, sources of water, fresh feed and salt could be used as attractants to concentrate numbers of feral camels, or to locate groups of feral camels for strategic management activities.

Trapping on water

With (note fonts and citations corrected):

"Camels have an ability to satisfy water needs during winter with moisture from grazed plants, so bodies of water, including habitually frequented waterholes (Lethbridge and Gee 2007), are likely to more often attract feral camels in summer (Schmidt-Nielsen 1964; Dörges and Heucke 1995). The concept of trapping on controlled water-points has been discussed for management of feral goats, feral horses and feral pigs (Dobbie *et al.* 1993; Choquenot *et al.* 1996; Parkes *et al.* 1996). Issues to address when using this technique include regular trap checks, trapping of non-target animals, presence of alternative, uncontrolled water sources, plus animal welfare issues arising from closing-down or fencing-off the alternative water-points (Parkes *et al.* 1996).

Locating on feed

Camels have a wide dietary preference (McCloy and Rowe 2000; Dörges and Heucke 2003; Dörges *et al.* 2003c) and a capacity to travel long distances (> 25 km per day) (Schmidt-Nielsen 1964; Grigg *et al.* 1995) in search of food. In areas where rainfall has a low long-term mean or is patchy and sporadic, feral camel movements tend to have a large range (Edwards *et al.* 2001) and erratic direction (Grigg *et al.* 1995). The camels' long appendicular skeleton enables them to travel with minimal muscular effort over these vast distances, and the (long) anatomy of their neck enables camels to not only graze low bushes and ground forbs, but also access tree foliage 3.5 metres off the ground (Phillips *et al.* 2001; Department of the Environment and Heritage 2004). Their vertical reach exceeds that of other herbivores in Australia, including that of goats (Grigg 2007). The combination of this camel-specific feeding behaviour and anatomy has enabled the feral camel to become a successful large herbivore in the Australian desert.

Camels are reputed to be capable of detecting distant water and fresh, green pasture (Grigg *et al.* 1995; Dörges and Heucke 2003). It thus follows that where rainfall has recently produced surface water or pasture growth, this has been associated with concentrated numbers of feral camels (Lethbridge and Gee 2007). 'Greenness' images from satellite remote sensing identify areas of recent rainfall and vegetation growth. The geographic location of the 'greenness' areas on satellite images could be targeted in searches for feral camel groups during destructive aerial culls. As a corollary, satellite remote sensing could also be used to identify areas of immediate flooding or fire that camels would avoid.

Attraction to salt

Camels have a capacity to drink saline water (Maloiy 1972) and eat plants with a high salt content (Schmidt-Nielsen 1964), so they often graze the dense herbage around salt lakes in winter (Dörges and Heucke 2003; Dörges *et al.* 2003b). Camels actually have a high requirement for supplementary salt (Wilson 1984; Department of the Environment and Heritage 2004). Salt lakes should consequently be targeted in searches for feral camel groups. It follows that strategic salt licks could be a part of planned entrapment programs.

In overview, through selective integration of techniques based on the attraction of feral camels to water, green feed and salt there is potential to improve current and future broad-scale management and monitoring of feral camels or their impacts.

3. Compliance to basic behaviours—herding, reproduction and habituation

Feral camels are herding animals and will actively seek out herd mates. Camel cows are most often within a herd, either in a harem with successful camel bulls (Dörges and Heucke 1995; Department of the Environment and Heritage 2004), or in a core group with young calves (Dörges and Heucke 1995). Camel bulls on the other hand may be found in a range of social situations relative to seasonal rut. Outside of rut they exist in the bachelor groups or in solitude (Dörges and Heucke 1995, 2003; Dörges *et al.* 2003d; Bertram *et al.* 2007).

'Judas' animal technique

The gender-specific herding and social behaviour of feral camels indicates an opportunity to undertake strategic management or monitoring activities with the assistance of a collared-camel cow and satellite- or radio-telemetry to locate it within a social group ('Judas' animal technique) (Edwards *et al.* 2004). This technique has been reported to be successful for control of strongly social species such as feral goats in populations of low density and where survivors of other control programs have become wary (Parkes *et al.* 1996). This technique has also been used in remote and inaccessible areas of the NT to eradicate cattle and buffalo that were difficult to sight or track in the final phase of the Brucellosis and Tuberculosis Eradication Campaign (BTEC). Success of the technique in the NT was increased by good collar design, tranquillisation for fitting of the collars, use of GPS co-ordinates to precisely pinpoint the location of animals, plus knowledge of animal behaviour to predict localised movements (Lehane 1996).

To-date, the 'Judas' animal technique has been considered most cost-effective for the final stages of a control program when time and financial costs are escalating. More recently, development in wireless sensors for wildlife, based on stationary grids or mobile peer-to-peer (ad hoc) networks (Juang *et al.* 2002), has indicated potential to use satellite-telemetry or radio-telemetry to monitor habitat use and movement by feral camel populations before and after programmed operations (Lethbridge and Gee 2007). These techniques could supplement or replace aerial surveys, which are currently the first option for detecting trigger thresholds for management activities (Lethbridge and Gee 2007).

Fertility control

Control of reproduction ('fertility control') is perceived to have a role in humane and cost-effective limitation of population growth for remote and free-ranging feral animals (Turner Jr. and Kirkpatrick 1986; Artois 1997; Williams 1997). It is therefore essential that the potential of fertility control is considered for feral camel populations, even though this potential is over-shadowed by both the role of adult survival in the slow maximum rate of population growth (7% to 10% per year) (Edwards *et al.* 2004; McLeod and Pople 2008), and the need for natural disaster (drought, disease) or conventional management methods (Commonwealth of Australia 1991) to precede or supplement fertility control.

Different methods of developed fertility control (Gonzalez *et al.* 1989; Hardy and Braid 2007) have all met with challenges (Nettles 1997; Bradley *et al.* 1999). Physical treatments to achieve fertility control in camels have included traditional use of intra-uterine devices (stones) to prevent conception (Sarna 2000, as per London 1999), open surgical castration (Manefield and Tinson 1997) and trials with sclerosing agents for chemical castration; the latter had no more than 50% success (Manefield and Tinson 1997).

Immunocontraception based on synthetic gonadotrophin releasing hormone (GnRH) has also been trialled in camels with little initial success (Manefield *et al.* 1997). If development of effective immunocontraception were to be attempted, consideration would also need to be given to issues such as timing, targeting and dissemination. These aspects of immunocontraception have been considered for other free-ranging and feral species. Timing of immunocontraception injections to correspond with seasonal breeding has improved the success rate for horses (Kirkpatrick *et al.* 1997) and provision of plant-derived immunocontraception at fenced water-points has been mooted for wildlife (Smith *et al.* 1997). Most recently, immunocontraception with natural transmission (dissemination) by an engineered virus-vector has been developed for foxes, mice, rabbits and Brushtail possums, but this has not been effectively launched (Hardy and Braid 2007; McLeod *et al.* 2007) on account of technical difficulties (Barlow 1997; McLeod *et al.* 2007) and perceived difficulties (Nettles 1997; Williams 1997; McLeod *et al.* 2007). This could redirect efforts to development of a 'bait' delivery technique for immunocontraception—even if the 'bait' delivery technique were subsequently shown to be more cost-effective with lethal 'baits' (McLeod *et al.* 2007). For feral camels, the concept of vectored immunocontraception has little potential (Lapidge *et al.* 2008). The camel mange mite (*Sarcoptes scabei* var. *cameli*) that is endemic in Australian camels may be considered a vector; however this skin parasite is capable of infesting other animals (Higgins 1985; Samuel *et al.* 2001) and is mildly zoonotic (Manefield and Tinson 1997). The best research proposition for fertility control of feral camels may be development of a 'bait' delivery technique (Lapidge *et al.* 2008), as considered for a humane biocide.

On reflection, the techniques with potential for development of fertility control in camels (immunocontraception delivered by injection or by 'bait') are only suitable for locally-restricted populations of camels ('behind wire'), where it is logistically and financially feasible to undertake the required repeat treatments (Lapidge *et al.* 2008). Fertility control based on currently available options has poor potential for the required broad-scale management of feral camels and their impacts. Even if a disseminating agent were identified for vectored immunocontraception, then as discussed for a biological disease agent, objections based on animal welfare and marketing issues would be likely to prohibit its use.

Habituation and evolution of behaviour

Development of management methods that are targeted to feral camels must take into consideration the camels' capacity to learn; there is potential for their learning experiences to produce behaviour that could either positively or negatively impact on the success of management activities. In the presence of perceived threats, camels tend to respond with grouping and vigilance at a distance by virtue of their herding behaviour, their long necks that permit elevated visual surveillance, and a large flight distance compared to other species (Primary Industries Standing Committee 2006). In the presence of familiarised and essential features, feral camels become habituated and develop memories. Recent radio-tracking studies of feral camels have described migration movement patterns and home range movement patterns, the latter of which have been related to memory of rock-hole (waterhole) and water-point locations in the remote landscape (Lethbridge and Gee 2007). Camels also learn the location of troughs and fences (Bertram *et al.* 2007), so this could be factored into strategic installation of infrastructure. To increase camels' memory and awareness of fence locations, and to potentially improve the effectiveness of those fences for exclusion of feral camels, various techniques may be employed to augment fence-lines. These techniques include use of electric fences to create an adversive association with location, or use of a 'camel-proved' fence with an 'aluminium-can' extension to improve visibility (Dörges and Heucke 2003; Bertram *et al.* 2007).

Feral camels can be 'trained' to enter trap-yards and access controlled water or feeds; however it follows that if individual feral camels remain or subsequently become trap-shy or 'bait'-shy, then a subset of the population may not be 'at risk', as would be required for a management option such as eradication (Braysher 1993; Bomford *et al.* 1995).

It may be difficult to avoid some of the changes in the behaviour, movement patterns, genetics or dynamics of animal populations that can evolve through ongoing vertebrate pest control activities (Hone 2007). Depending on the physiological and behavioural characteristics of a pest animal population, it is even possible for fertility control to result in a paradoxical population increase in an area and a commensurate increase in negative impacts. This can occur either through increased survival of the breeding-age females and increased reproduction in 'survivors', or through immigration of young adults into a depopulated area (McLeod *et al.* 2007). The first two effects arise from increased feed availability; the latter effect would be of concern with feral camel populations.

Knowledge of feral camel behaviour enables forward planning, which either helps to avoid and minimise behaviour patterns that are contrary to successful management, or encourages behaviour patterns that may promote and improve methods for managing feral camels and their impacts. This includes use of predictive models to improve targeting of management methods for cost-effective monitoring or post-control evaluation of feral camel populations in remote locations (Lethbridge and Gee 2007). Knowledge of feral camel behaviour also has potential to promote development of repellents to control the negative impacts of feral camels. Repellents in general are tactical, non-lethal methods for controlling damage by pests (Hone 2007). Information is available about fencing methods (Dörges and Heucke 2003; Bertram *et al.* 2007) to passively repel feral camels, but limited information is available regarding the factors that actively repel feral camels and how these factors could be used for development of a camel repellent.

The points highlighted in the three subsections above are encapsulated in Table 1 with a summary showing where management methods actively or passively exploit Achilles' heel aspects of the camel. Table 1 also indicates which management methods are 'ideal' based on extrapolated criteria of an 'ideal' vertebrate pest control method (McLeod *et al.* 2007) and requirements for broad-scale management of feral camels and their impacts. The last two columns of Table 1 indicate which management methods are currently used and which methods are recommended as suitable for improvement or development; these recommended methods are addressed in the final discussion.

Discussion

Achilles' heel aspects

As indicated in Table 1, active or passive exploitation of one or more Achilles' heel aspects is already intrinsic to current and potential methods for managing feral camels and their impacts. Aspects of camel-specific behaviour are exploited by all management methods, and aspects of camel-specific physiology or anatomy are exploited by more than half of the listed methods. This highlights the importance of considering camel behaviour, in particular, for the planning, implementation and review of any feral camel management activity.

In the final discussion point (*Complementary management to improve outcomes*), feral camel management activity is reviewed according to the potential for complementary management to improve or develop recommended management methods. This review is inclusive of multiple Achilles' heel aspects of feral camels.

Table 1. Methods for managing feral camels and their impacts, relative to exploited Achilles' heel aspects, 'ideal' criteria, current use and recommendations with respect to broad-scale management

Management approach (Key #1)	**Exploited Achilles' heel aspects**				**Ideal' criteria (Key #2)**					**Use**	
Management Method	Health Risk	Physiology	Anatomy	Behaviour	Targeted	Humane	Propagated	Cost-Effective	Ready	Current	Authors' Recommend
Monitoring & locating											
Aerial survey	✗	✗	✓	✓	✓	✓	—	[C]	✓	✓	✓
Ground survey	✗	[C]	✓	✓	✓	✓	—	[C]	✓	✓	✓
Satellite remote sensing	✗	[C]	✓	✓	—	—	—	✓	✓	✗	✓
Habitat modelling	✗	✓	✗	✓	✓	—	—	[??]	✗	✗	✓
Attractant	✗	✓	✓	✓	[C]	[??]	✗	[??]	✗	✗	✓
'Judas' animal technique	✗	✗	✗	✓	✓	[C]	✓	[C]	✓	✗	✓
Wireless sensor networking	✗	✓	✓	✓	✓	[??]	✓	[??]	✗	✗	[??]
Bio-control											
Camel-specific pathogen	✓	[??]	[??]	✓	✓	[??]	[??]	[??]	✗	✗	✗
Humane biocide	✓	✓	✓	✓	[??]	[??]	✗	[??]	✗	✗	✓
Oral / Immunocontraception	✗	✓	✗	✓	[??]	[??]	[??]	[??]	✗	✗	✗
Destocking											
Destructive aerial cull	✗	✗	✓	✓	✓	✓	✗	[C]	✓	✓	✓
Destructive ground cull	✗	✗	✓	✓	✓	[C]	✗	[C]	✓	✓	✓
On-site 'pet-meat' slaughter	✗	✗	✓	✓	✓	✓	✗	[C]	✓	✓	✓
On-site 'game-meat' slaughter	✗	✗	✓	✓	✓	✓	✗	[C]	[C]	✗	✓
On-site abattoir slaughter	✗	✗	✓	✓	✓	✓	✗	[??]	✗	✗	✓
Trap into yard or paddock	✗	✓	✓	✓	✗	✓	[C]	[C]	✓	✓	✓
Muster	✗	✗	✓	✓	✓	✓	✗	[C]	✓	✓	✓
Exclusion											
Physical fencing	✗	✓	✓	✓	[C]	[C]	✓	✗	✓	✓	✗
Electric fencing	✗	✓	✗	✓	[C]	[C]	✓	✗	✓	✓	✗
Audio-visual fencing	✗	✓	✓	✓	[C]	[C]	✓	✗	✓	✓	✗
Repellents	✗	[??]	[??]	✓	[??]	[??]	[??]	[??]	✗	✗	[??]

Presence of Aspects or Criteria

✓ Yes ✗ No [C] Conditional [??] Unknown — Nil application

Key #1

Management approach	Description	Examples of Exploited Achilles' Heel Aspects
Monitoring & locating	Monitor and survey the distribution and movement of feral camels, plus their use of habitat, before and after management operations.	Seasonal attraction to salt, water or green grass. Specific habitat use—wide dietary range, high mobility. Herding of cow-groups and bachelor-groups.
Bio-control	Indirect reduction of a feral camel population using biological methods, such as pathogens, humane biocides and contraception.	Pathogenicity or toxicity highly specific to camels. Delivery promoted by herding or camel-specific attractants. Delivery timing targeted to seasonal rut.
Destocking	Direct reduction of a feral camel population using destruction and commercial harvesting, including trapping and mustering for domestication, live export and abattoir slaughter operations off-site.	Seasonal attraction to salt or water. Grouping, vigilance and familiarisation.
Exclusion	Exclusion of feral camels from designated areas, such as waterholes, airstrips and remote community housing.	Memory, learning and familiarisation.

Key #2

'Ideal' Criteria	Description
Targeted	Target-specific for feral camels, so there are no effects on other animal species and no adverse impacts on the environment or human contacts.
Humane	Humane method with potential for suffering either avoided or alleviated using documented 'best practice' methods[1].
Propagated	Effects persist or spread in the feral camel population.
Cost-effective	Cost-effective for broad-scale[2] management or monitoring, including consideration of efficacy and logistics of implementation.
Ready	Ready technique that has no logistical, developmental, registration or approval impediments to implementation for vertebrate pest management in Australia.

[1] e.g. Primary Industries Standing Committee 2006. Model Code of Practice for the Welfare of Animals, The Camel (*Camelus dromedarius*), PISC Report 86. 2nd ed. CSIRO Publishing, Collingwood, Vic.

[2] Only broad-scale implications are considered, based on areas that exceed the geographic range of feral camels (4,900 km^2) (Edwards et al. 2001).

'Ideal' criteria for management methods

Table 1 has also indicated the limited extent to which listed methods for managing feral camels and their impacts address conventional criteria for an 'ideal' management method. Although other criteria that have not been assessed here are important determinants of 'appropriateness' within local demographic and geographic contexts of a vertebrate pest control method (McLeod *et al.* 2007), these criteria are considered in the nation-wide management framework developed by the DKCRC (Edwards *et al.* 2008). For example, consideration of ethical, legal, political and social criteria is relevant to the use of destructive aerial culling to manage feral camels and their impacts; this management method is generally acceptable for pastoralists, but is not necessarily acceptable for other stakeholders.

Management methods—not recommended

Three currently-used methods of exclusion fencing are not recommended for broad-scale management of feral camels and their impacts. Exclusion fencing is not cost-effective over large areas but does have application for the protection of localised areas of high value (Saalfeld and Zeng 2008).

Recommendations have been withheld for two currently-unused management methods that have insufficient information to make an informed recommendation (wireless sensor networking, repellents). Another two currently-unused management methods (camel-specific pathogen, oral / immunocontraception) have not been recommended outright for broad-scale bio-control of feral camels. Camel-specific pathogens entail multiple concerns about animal welfare, marketing and national biosecurity. Oral or immunocontraception would only be suitable for a locally-restricted camel population; neither would be suitable for management of free-ranging camel populations.

Management methods—recommended

With the exception of exclusion fencing, all management methods that are currently used for the management of feral camels and their impacts have been recommended for continued use. These methods are able to demonstrate satisfactory humaneness and cost-effectiveness in some or all situations of potential broad-scale management.

Management methods that are currently unused but recommended include satellite remote sensing, habitat modelling, attractant and 'Judas' animal technique. These methods are considered to have potential to complement currently-used broad-scale approaches to management (see details discussed below), but they all have some 'unknown' aspects in relation to the 'ideal' criteria. Habitat modelling and attractants in particular would need further investigation or development before use in this capacity.

Other currently-unused but recommended methods are humane biocide, on-site 'game-meat' slaughter and on-site abattoir slaughter. At this stage, humane biocide is not 'ready' and only has enough potential to warrant investigation of relevant toxic chemicals, associated animal welfare issues and camel-specific delivery techniques that circumvent non-target effects. In comparison, on-site 'game-meat' and abattoir slaughter operations could be developed relatively quickly. Their use could help realise the additional advantages of integrated destocking (Braysher 1993) that offset the cost of destructive culling. These on-site slaughter operations would benefit from the knowledge of current on-site pet-meat slaughter operations, as well as from the improvement of outcomes with complementary use of other management methods.

Complementary management to improve outcomes

For survey methods and destocking approaches that are recommended for broad-scale management of feral camels and their impacts, there is scope for improvement of outcomes if complementary management methods are used to help predict, locate or concentrate feral camels. Examples of improvements are discussed below:

Habitat modelling provides an opportunity for stratification by habitat type to improve handling of heterogeneity in survey data; this would improve precision and reduce bias in population estimates (Buckland *et al.* 1993) for both aerial and ground surveys. Together with satellite remote sensing that detects (attractive) seasonal green feed growth, surface water and (aversive) recent fire-scars, habitat modelling could also help predict the location of feral camels for all destocking approaches—especially for aerial and ground culling. This relates to the potential for proactive use of limited or controlled waters as attractants.

Where surface water within a limited area is a source of attraction, this could help locate and concentrate feral camels for mustering or destructive culling; as a corollary, absence of ephemeral waters or closure of controlled water-points outside of a destock area would help limit dispersion of camels away from the destock area—especially during summer. Thus locating of ephemeral waters by satellite remote sensing together with knowledge of controlled waters from pastoral maps could improve planning for trapping and mustering of feral camels. A controlled water-point will remain a basic focus of attraction for yard-trapping of feral camels, and for this, both drinking behaviour and rutting behaviour will be major considerations. These behaviours create problems for trapping-on-water during the winter months—a period when feral camels are less likely to drink water and bull camels are in rut. At this time, the bull camels are more likely to engage in inter-male aggression, pursue female camels, kill peri-natal calves (Dörges and Heucke 1995) and destroy infrastructure such as fences. This highlights a potential for yard and fence damage, a need for diligence in trap checks and a need for trap, yard and race design that can accommodate the behaviour and physical capacity of camels.

Herding behaviour and salt also have potential as attractants to improve the effectiveness of destocking approaches. Where herding behaviour is a source of attraction and feral camels see others present in a trap-yard with no perceived danger, this may encourage more to enter the yard. Herding behaviour also has a role in the 'Judas' animal technique, either to improve the efficiency of mustering and destructive aerial culling, or to a limited extent, to improve targeting for mustering and destructive ground culling. Some of the reasons that the 'Judas' animal technique has been used for other vertebrate pest species (low population density in regions, high cost of time and finance for ongoing management activities) are applicable to feral camel populations in some situations.

Finally, where salt is a source of attraction, use of this may not only assist trapping and mustering, but may also assist research and development for delivery of a humane biocide.

Conclusion

In answer to our initial question: "Yes, the feral camel does have Achilles' heel aspects, many of which are actively exploited by currently-used methods in the odyssey of managing feral camels and their impacts." This paper has promoted consideration of the Achilles' heel concept and, in the process, identified opportunities to either improve current methods or develop potential methods of broad-scale management. Particular consideration has been given to the situations where management outcomes could be improved with exploitation of camel-specific behaviour.

Key recommendations for broad-scale management of feral camels and their impacts include continued use of aerial survey, ground survey, destructive aerial culling, destructive ground culling, on-site pet meat slaughter, trapping and mustering. A review of opportunities for complementary use of (additional) management methods to improve outcomes of survey methods and destocking approaches is also recommended. Although currently used for the protection of localised areas of high value, exclusion fencing is not recommended for use over large areas on account of the prohibitive cost. Complementary use of management methods should be undertaken in conjunction with development or investigation of seven currently-unused management methods (satellite remote sensing, habitat modelling, attractant, 'Judas' animal technique, humane biocide, on-site 'game-meat' slaughter, on-site abattoir slaughter).

Review, improvement and development of management techniques for bio-control and destocking of feral camels are in line with the expectations of the major animal welfare groups. Use of complementary management methods helps support a strategy of integrated vertebrate pest management.

Acknowledgements

The authors would like to acknowledge the inspiration provided by Dr. Birgit Dörges, Dr. Jürgen Heucke and Prof. Gordon Grigg through their seminal research into feral camels in central Australia.

The work reported in this publication is supported by funding from the Australian Government Cooperative Research Centres Programme through the Desert Knowledge Co-operative Research Centre (DKCRC) and through the National Heritage Trust; the views expressed herein do not necessarily represent the views of DKCRC or its participants.

References

Agab, H. 2006. Diseases and causes of mortality in a camel (*Camelus dromedarius*) dairy farm in Saudi Arabia. *Journal of Camel Practice and Research* **13**: 165-69.

Agriculture Western Australia 2005. *Feral camel [Western Australia]*. Agriculture Western Australia (online) Available: [http://www.agric.wa.gov.au/pls/portal30/docs/FOLDER/IKMP/PW/VP/FER/F12200.PDF] Accessed Oct. 2007.

Artois, M. 1997. Managing problem wildlife in the 'Old World': a veterinary perspective. *Reproduction, Fertility and Development* **9**: 17-26.

Australian Pest Animal Strategy – A national strategy for the management of vertebrate pest animals in Australia 2007. Natural Resource Management Ministerial Council, Canberra.

Australian Pesticides and Veterinary Medicines Authority n.d. *About the APVMA*. Australian Government (online) Available: [http://www.apvma.gov.au/index.asp] Accessed Dec. 2007.

Bardsley, D. 2007. *I think it's a toxin, not a disease*. Al Nisr Publishing LLC (online) Available: [http://archive.gulfnews.com/articles/07/08/20/10147869.html] Accessed Nov. 2007.

Barker, P. and Rich, E. (comp.) 2007. *BUSH TECH #35, Protecting Your Water Places*. Centre for Appropriate Technology, Alice Springs; Greening Australia, Northern Territory (online) Available: [http://www.icat.org.au/media/Resources/integrated%20services/bushtech%2035%20lo%20res.pdf] Accessed Jan. 2008.

Barlow, N.D. 1997. Modelling immunocontraception in disseminating systems. *Reproduction, Fertility and Development* **9**: 51-60.

Barnett, J. and Jongman, E.C. 1996. Techniques for the assessment of humaneness and measuring pain and stress in animals. Pp. 22-26 in *Humaneness and vertebrate pest control: Proceedings of the seminar held on March 27th 1996, Report Series Number 2*, edited by P. Fisher and C.A. Marks, Agriculture Victoria, Department of Natural Resources and Environment, Melbourne.

Bergin, T.J. and Torenbeeck, L.R. 1991. Melioidosis in camels. *Australian Veterinary Journal* **68**: 309.

Bertram, J., Williams, O., Gill, B., Coventry, J. and Seidel, P. (rev.ed.) 2007. Camel Control Using Alternative Fencing. *Northern Territory Department of Primary Industry, Fisheries and Mines, Agnote J16*: 1-4. Available: Technical Publications, Northern Territory Department of Resources.

Bogner, P., Csutora, P., Cameron, I.L., Wheatley, D.N. and Miseta, A. 1998. Augmented water binding and low cellular water content in erythrocytes of camel and camelids. *Biophysical Journal* **75**: 3085-91.

Bomford, M. and O'Brien, P. 1995. Eradication or control for vertebrate pests? *Wildlife Society Bulletin* **23**: 249-55.

Booth, N.H. and McDonald, L.E. (Eds) 1982. *Veterinary Pharmacology and Therapeutics*. 5th ed. The Iowa State University Press, Ames.

Bradley, M.P., Eade, J., Penhale, J. and Bird, P. 1999. Vaccines for fertility regulation of wild and domestic species. *Journal of Biotechnology* **73:** 91-101.

Braysher, M.L. 1993. *Managing Vertebrate Pests: Principles and Strategies*. Australian Government Publishing Service, Canberra.

Brian, J. 2005. *Hoosh! Camels in Australia*. ABC Books for the Australian Broadcasting Corporation, Sydney.

Brown, A. 2004. Camel - A review of diseases in central Australia. *Northern Territory Department of Primary Industry, Fisheries and Mines, Technical Bulletin 314*: 1-16. Available: Technical Publications, Northern Territory Department of Resources.

Buckland, S.T., Anderson, D.R., Burnham, K.P. and Laake, L.J. 1993. *Distance Sampling: Estimating abundance of biological populations*. Chapman and Hall, London.

Choquenot, D., McIlroy, J., Korn, T. and Bomford, M. (Ed.) 1996. *Managing Vertebrate Pests: Feral Pigs*. Australian Government Publishing Service, Canberra.

Clarke, E.G.C. and Clarke, M.L. 1975. *Veterinary Toxicology*. reprinted 1st ed. Bailliere Tindall, London.

Commonwealth of Australia 1991. *Culling of Large Feral Animals in the Northern Territory: Report by the Senate Select Committee on Animal Welfare*. Parliament of the Commonwealth of Australia, Canberra.

Department of the Environment and Heritage 2004. *The feral camel (Camelus dromedarius)*. Department of the Environment and Water Resources (online) Available: [http://www.environment.gov.au/biodiversity/invasive/publications/camel/index.html#download] Accessed Sept. 2007.

Dobbie, W.R., Berman, D.M. and Braysher, M.L. 1993. *Managing Vertebrate Pests: Feral Horses*. Australian Government Publishing Service, Canberra.

Done, S.H., Lees, P., Dansie, O. and Watkins, L.W. 1975. Sedation and restraint of fallow deer with diazepam. *British Veterinary Journal* **131**: 545-48.

Dörges, B. and Heucke, J. 1995. *Ecology, Social Organization and Behaviour of the Feral Dromedary (Camelus dromedarius) (L. 1758) in Central Australia*. (unpublished translation of two dissertations) University of Braunschweig, Braunschweig. Available: Arid Zone Research Institute Library, NT-DPIFM Alice Springs NT; Sustainable Ecosystems - Centre for Arid Zone Research Library, CSIRO Alice Springs NT.

Dörges, B. and Heucke, J. 2003. *Demonstration of ecologically sustainable management of camels on aboriginal and pastoral land, Final report on project number: 200046*. Natural Heritage Trust (online) Available: [http://www.camelsaust.com.au/NHTreport2003.doc] Accessed Dec. 2007.

Dörges, B., Heucke, J. and Dance, R. 2003a. Observations on the effects of camel grazing on the vegetation of central Australia. *Northern Territory Department of Primary Industry, Fisheries and Mines, Technote* **118**: 1-5. Available: Technical Publications, Northern Territory Department of Resources.

Dörges, B., Heucke, J. and Dance, R. 2003b. Sustainable stocking rates for camels in central Australia. *Northern Territory Department of Primary Industry, Fisheries and Mines, Technote* **117:** 1-3. Available: Technical Publications, Northern Territory Department of Resources.

Dörges, B., Heucke, J. and Dance, R. 2003c. The palatability of central Australian plant species to camels. *Northern Territory Department of Primary Industry, Fisheries and Mines, Technote* **116:** 1-8. Available: Technical Publications, Northern Territory Department of Resources.

Dörges, B., Heucke, J.F., Coventry, J., Coppock, G.A., Beard, L.A. and Grigg, G.C. 2003d. Body temperature in free ranging dromedary camels (poster abstract). *Comparative Biochemistry and Physiology, Part-A Molecular and Integrative Physiology* **134A**: S7-S8.

Edwards, G. 2008a. *Outcomes and recommendations of the Feral Camel Action Plan Workshop, 13-14 April 2005, DKCRC Working Paper 25.* Desert Knowledge CRC (online) Available: [http://www.desertknowledgecrc.com.au/downloads/DKCRC-Working-Paper-25-Camel-project-April-2005-Workshops.pdf] Accessed Aug. 2008.

Edwards, G.P. 2008b. *Background to the project. Pp. 1-8. in Managing the impacts of feral camels in Australia: a new way of doing business, DKCRC Report 47, edited by G.P. Edwards, B. Zeng, W.K. Saalfeld, P. Vaarzon-Morel and M. McGregor.* Desert Knowledge CRC, Alice Springs (online) Available: [http://www.desertknowledgecrc.com.au/publications/] Accessed Dec. 2009.

Edwards, G.P., Eldridge, S.R., Wurst, D., Berman, D.M. and Garbin, V. 2001. Movement patterns of female feral camels in central and northern Australia. *Wildlife Research* **28**: 283-89.

Edwards, G.P., Saalfeld, K. and Clifford, B. 2004. Population trend of feral camels in the Northern Territory, Australia. *Wildlife Research* **31**: 509-17.

Edwards, G.P., McGregor, M., Zeng, B., Saalfeld, W.K., Vaarzon-Morel, P. and Duffy, M. 2008. *Synthesis and key recommendations. Pp. 331-360. in Managing the impacts of feral camels in Australia: a new way of doing business, DKCRC Report 47, edited by G.P. Edwards, B. Zeng, W.K. Saalfeld, P. Vaarzon-Morel and M. McGregor.* Desert Knowledge CRC, Alice Springs (online) Available: [http://www.desertknowledgecrc.com.au/publications/] Accessed Dec. 2009.

el-Khouly, A.B., Gadir, F.A., Cluer, D.D. and Manefield, G.W. 1992. Aspergillosis in camels affected with a specific respiratory and enteric syndrome. *Australian Veterinary Journal* **69**: 182-86.

Gee, P. 2007. *pers. com.* (e:mail) NT Department of Natural Resources, Environment and the Arts, Alice Springs, NT.

Gitao, C.G. 1994. Outbreaks of contagious ecthyma in camels (*Camelus dromedarius*) in the Turkana district of Kenya. *Revue scientifique et technique (International Office of Epizootics)* **13**: 939-45.

Gonzalez, A., Allen, A.F., Post, K., Mapletoft, R.J. and Murphy, B.D. 1989. Immunological approaches to contraception in dogs. *Journal of Reproduction and Fertility - Supplement*: 189-98.

Government of South Australia 2003. *Policy on Camels in South Australia*. Department of Water, Land and Biodiversity Conservation (online) Available: [http://www.dwlbc.sa.gov.au/assets/files/lbsap_CamelPolicy_2003_nrm.pdf] Accessed Sept. 2007.

Greening Australia 2005. *Annual Report 2004 - 2005: growing the future together*. Greening Australia, Northern Territory (online) Available: [http://live.greeningaustralia.org.au/NR/rdonlyres/4DE208DF-E443-4FE5-8B95-57500996E899/4563/GA_Annual_Report_05.pdf] Accessed Dec. 2007.

Gregory, G. 1996. Perception of pain associated with 1080 poisoning. Pp. 62-64 in *Humaneness and vertebrate pest control: Proceedings of the seminar held on March 27th 1996, Report Series Number 2*, edited by P. Fisher and C.A. Marks, Agriculture Victoria, Department of Natural Resources and Environment, Melbourne.

Grigg, G. 2007. Foreword: One zoologist's reflections about our arid and semi-arid interior and its future. Pp. vii-xvi in *Animals of arid Australia: out on their own?*, edited by C. Dickman, D. Lunney and S. Burgin, Royal Zoological Society of New South Wales, Mosman, N.S.W.

Grigg, G.C., Pople, A.R. and Beard, L.A. 1995. Movements of feral camels in central Australia determined by satellite telemetry. *Journal of Arid Environments* **31**: 459-69.

Hardy, C.M. and Braid, A.L. 2007. Vaccines for immunological control of fertility in animals. *Revue scientifique et technique (International Office of Epizootics)* **26**: 461-70.

Higgins, A.J. 1985. The camel in health and disease. 4. Common ectoparasites of the camel and their control. *British Veterinary Journal* **141**: 197-216.

Hone, J. 2007. *Wildlife Damage Control*. CSIRO Publishing, Collingwood, Victoria.

Huntington, P.J., Chapman, C.B. and Dyer, R. 1993. Nervous disorders caused by accidental ingestion of a deer catch mix in 18 horses. *Australian Equine Veterinarian* **11**: 67, 69.

Jezek, Z., Kríz, B. and Rothbauer, V. 1983. Camelpox and its risk to the human population. *Journal of Hygiene, Epidemiology, Microbiology and Immunology* **27**: 29-42.

Juang, P., Oki, H., Wang, Y., Martonosi, M., Peh, L. and Rubenstein, D. 2002. *Energy-efficient computing for wildlife tracking: Design tradeoffs and early experiences with zebranet*. Princeton University (online) Available: [http://www.princeton.edu/~peh/publications/znet.pdf] Accessed Dec. 2007.

Kirkpatrick, J.F., Turner Jr., J.W., Liu, I.K., Fayrer-Hosken, R. and Rutberg, A.T. 1997. Case studies in wildlife immunocontraception: wild and feral equids and white-tailed deer. *Reproduction, Fertility and Development* **9**: 105-10.

Koenig, R. 2007. Camel scientists ask: What's sinking the ships of the desert? *Science* **318**: 1372-73.

Lapidge, S.J., Eason, C.T. and Humphrys, S.T. 2008. *A review of chemical, biological and fertility control options for the camel in Australia, DKCRC Report 51.* Desert Knowledge CRC, Alice Springs (online) Available: [http://www.desertknowledgecrc.com.au/publications/] Accessed Dec. 2009.

Lehane, R. 1996. *Beating the Odds in a Big Country: The Eradication of Bovine Brucellosis and Tuberculosis in Australia*. CSIRO Publishing, Collingwood, Victoria.

Lethbridge, M.R. and Gee, P. (unpub.) 2007. *Final Report - 2007 Camel Aerial Survey of South Australia and Western Australia.* Flinders University; Rural Solutions, South Australia.

Lindeman, M. and Orchard, F. (comp.) 2004. *Vertebrate Pest Research: A Resource Book of Publications 1995-2003*. Feb. 2004 ed. Primary Industries Research, Frankston, Victoria.

Maloiy, G.M.O. 1972. Renal salt and water excretion in the camel (*Camelus dromedarius*). Pp. 243-59 in *Comparative Physiology of Desert Animals*, edited by G.M.O. Maloiy, Academic Press, London.

Manefield, G.W. and Tinson, A.H. 1997. *Camels: A Compendium*. Feb. 1997 ed. The University of Sydney Post Graduate Foundation in Veterinary Science, Sydney.

Marks, C.A. 1996. Research directions for humane burrow fumigation and 1080 predator baiting. Pp. 50-57 in *Humaneness and vertebrate pest control: Proceedings of the seminar held on March 27th 1996, Report Series Number 2*, edited by P. Fisher and C.A. Marks, Agriculture Victoria, Department of Natural Resources and Environment, Melbourne.

McCloy, L. and Rowe, P. 2000. *Assessing the Potential for a Commercial Camel Industry in Western Australia: A Report for the Rural Industries Research and Development Corporation*. Rural Industries Research and Development Corporation (online) Available: [http://www.austcamel.com.au/library/waassess.pdf] Accessed Oct. 2007.

McLeod, S.R., Saunders, G., Twigg, L.E., Arthur, A.D., Ramsey, D. and Hinds, L.A. 2007. Prospects for the future: is there a role for virally vectored immunocontraception in vertebrate pest management? *Wildlife Research* **34**: 555-66.

McLeod, S.R. and Pople, A.R. 2008. *Modelling options for management of feral camels in central Australia, DKCRC Report 48.* Desert Knowledge CRC, Alice Springs (online) Available: [http://www.desertknowledgecrc.com.au/publications/] Accessed Dec. 2009.

Musa, M.T. and Osman, O.M. 1990. An outbreak of suspected tick paralysis in one-humped camels (*Camelus dromedarius*) in the Sudan. *Revue d'Élevage et de Médecine Vétérinaire des Pays Tropicaux* **43**: 505-10.

Nettles, V.F. 1997. Potential consequences and problems with wildlife contraceptives. *Reproduction, Fertility and Development* **9**: 137-43.

New Scientist Environment and Reuters 2007. *Australian drought provokes wild camel rampage*. NewScientist.com news service (online) Available: [http://environment.newscientist.com/article.ns?id=dn11379&feedId=earth_rss20] Accessed Aug. 2007.

Oogjes, G. 1996. The ANZFAS view of vertebrate pest control using chloropicrin fumigation and 1080 poisoning. Pp. 9-12 in *Humaneness and vertebrate pest control: Proceedings of the seminar held on March 27th 1996, Report Series Number 2*, edited by P. Fisher and C.A. Marks, Agriculture Victoria, Department of Natural Resources and Environment, Melbourne.

Oogjes, G. 1997. Ethical aspects and dilemmas of fertility control of unwanted wildlife: an animal welfarist's perspective. *Reproduction, Fertility and Development* **9**: 163-67.

Osman, N., El-Sabban, F.F., Al Khawli, A. and Mensah-Brown, E.P. 2004. Effect of foodstuff contamination by aflatoxin on the one-humped camel (*Camelus dromedarius*) in Al Ain, United Arab Emirates. *Australian Veterinary Journal* **82**: 759-61.

Parkes, J., Henzell, R., Pickles, G. and Bomford, M. (Ed.) 1996. *Managing Vertebrate Pests: Feral Goats*. Australian Government Publishing Service, Canberra.

Peeters, P.J., Jennings, S., Carpenter, R.J. and Axford, G. 2005. *Assessing the Abundance and Impacts of Feral Camels in the Great Victoria Desert: A Report to the Aboriginal Lands Integrated Natural Resource Management Group*. Department for Environment and Heritage, South Australia (online) Available: [http://www.environment.sa.gov.au/biodiversity/arkoneyre/pdfs/feral_camels_report.pdf.] Accessed Oct. 2007.

Pfeffer, M., Neubauer, H., Wernery, U., Kaaden, O.R. and Meyer, H. 1998. Fatal form of camelpox virus infection. *The Veterinary Journal* **155**: 107-09.

Phillips, A., Dörges, B., Heucke, J. and O'Reilly, G. 2001. *Co-grazing Cattle and Camels: A Report for the Rural Industries Research and Development Corporation*. Rural Industries Research and Development Corporation (online) Available: [http://www.rirdc.gov.au/reports/NAP/01-092.pdf] Accessed Oct. 2007.

Primary Industries Standing Committee 2006. *Model Code of Practice for the Welfare of Animals, The Camel (Camelus dromedarius), PISC Report* 86. 2nd ed. CSIRO Publishing, Collingwood, Victoria.

ProMED 2006. *Undiagnosed camel disease - Ethiopia: Request for information*. International Society for Infectious Diseases (online) Available: [http://www.promedmail.org/pls/promed/f?p=2400:1001:26016179402061100::NO::F2400_P1001_BACK_PAGE,F2400_P1001_PUB_MAIL_ID:1010,34478] Accessed Nov. 2007.

Radostits, O.M., Gay, C.C., Hinchcliff, K.W. and Constable, P.D. 2007. *Veterinary Medicine: A textbook of the diseases of cattle, horses, sheep, pigs, and goats*. 10th ed. Saunders Elsevier, Edinburgh.

Saalfeld, W.K. and Edwards, G.P. 2008. *Ecology of feral camels in Australia. Pp. 9-34. in Managing the impacts of feral camels in Australia: a new way of doing business, DKCRC Report 47, edited by G.P. Edwards, B. Zeng, W.K. Saalfeld, P. Vaarzon-Morel and M. McGregor.* Desert Knowledge CRC, Alice Springs (online) Available: [http://www.desertknowledgecrc.com.au/publications/] Accessed Dec. 2009.

Saalfeld and Zeng 2008. *Review of non-commercial control methods for feral camels in Australia. Pp. 183-219. in Managing the impacts of feral camels in Australia: a new way of doing business, DKCRC Report 47, edited by G.P. Edwards, B. Zeng, W.K. Saalfeld, P. Vaarzon-Morel and M. McGregor.* Desert Knowledge CRC, Alice Springs (online) Available: [http://www.desertknowledgecrc.com.au/publications/] Accessed Dec. 2009.

Samuel, W.M., Pybus, M.J., Kocan, A.A. and Davis, J.W. (Eds) 2001. *Parasitic Diseases of Wild Mammals*. 2nd ed. Iowa State University Press, Ames.

Sarna, J.R. 2000. *Contraception in the ancient times*. The University of Calgary (online) Available: [http://www.hom.ucalgary.ca/Dayspapers2000.pdf#page=27] Accessed Nov. 2007.

Scenta 2007. *Solving the puzzle of camel death*. Science Worlds (online) Available: [http://www.sciencenet.org.uk/news.cfm?faarea1=theme1.contentItem_show_1&cit_id=4795] Accessed Nov. 2007.

Schmidt-Nielsen, K. 1964. Chapter 3. The Camel. Pp. 33-70 in *Desert Animals: Physiological problems of heat and water*, edited, Clarendon Press, Oxford.

Schmidt-Nielsen, K. 1990. *Animal Physiology: Adaptation and Environment*. 4th ed. Cambridge University Press, New York.

Schroter, R.C., Zine Filali, R., Brain, A.P., Jeffery, P.K. and Robertshaw, D. 1990. Influence of dehydration and watering on camel red cell size: a scanning electron microscopic study. *Respiration Physiology* **81**: 381-90.

Sena, D.S., Gorakh-Mal, Sharma, N. and Sahani, M.S. 2006. Calf mortality in camels: a report. *Journal of Camel Practice and Research* **13**: 171-72.

Singer, P. 1997. Neither human nor natural: ethics and feral animals. *Reproduction, Fertility and Development* **9**: 157-62.

Smith, G., Walmsley, A. and Polkinghorne, I. 1997. Plant-derived immunocontraceptive vaccines. *Reproduction, Fertility and Development* **9**: 85-89.

Smith, J.E., Mohandas, N. and Shohet, S.B. 1979. Variability in erythrocyte deformability among various mammals. *American Journal of Physiology* **236**: H725-H30.

Smith, M.A. 1986. Impacts of feral horses grazing on rangelands: An overview. *Journal of Equine Veterinary Science* **6**: 236-38.

Thomas, J.W., Robinson, R.M. and Marburger, R.G. 1967. Use of diazepam in the capture and handling of cervids. *The Journal of Wildlife Management* **31**: 686-92.

Turner Jr., J.W. and Kirkpatrick, J.F. 1986. Fertility control as a management tool for feral horse populations. *Journal of Equine Veterinary Science* **6**: 278-84.

Vaarzon-Morel, P. 2008. *Key stakeholder perceptions of feral camels: Aboriginal community survey. Pp. 79-124. in Managing the impacts of feral camels in Australia: a new way of doing business, DKCRC Report 47, edited by G.P. Edwards, B. Zeng, W.K. Saalfeld, P. Vaarzon-Morel and M. McGregor.* Desert Knowledge CRC, Alice Springs (online) Available: [http://www.desertknowledgecrc.com.au/publications/] Accessed Dec. 2009.

Wernery, U., Kaaden, O.-R. and Buzanoski, J.H. (trans.) 1995. *Infectious Diseases of Camelids*. 1st ed. Blackwell Wissenschafts-Verlag, Berlin.

Williams, C.K. 1997. Development and use of virus-vectored immunocontraception. *Reproduction, Fertility and Development* **9**: 169-78.

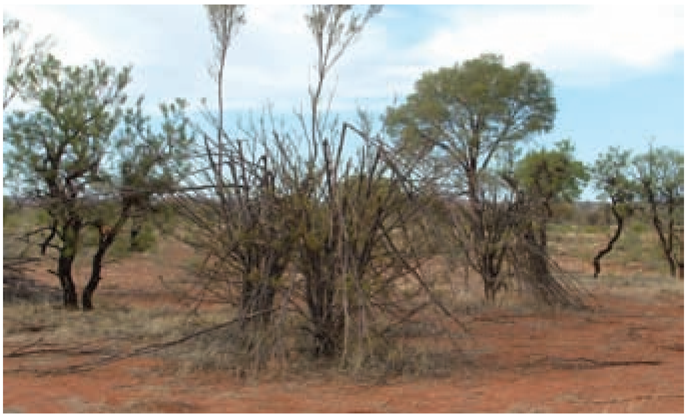
Wilson, R.T. 1984. *The Camel*. Longman, Essex.

Zeng, B. and McGregor, M. 2008. *Review of commercial options for management of feral camels. Pp. 221-282. in Managing the impacts of feral camels in Australia: a new way of doing business, DKCRC Report 47, edited by G.P. Edwards, B. Zeng, W.K. Saalfeld, P. Vaarzon-Morel and M. McGregor.* Desert Knowledge CRC, Alice Springs (online) Available: [http://www.desertknowledgecrc.com.au/publications/] Accessed Dec. 2009.

APPENDIX I

Camels in woodland near Docker River, NT.

Photo, K. Schwartzkopff.

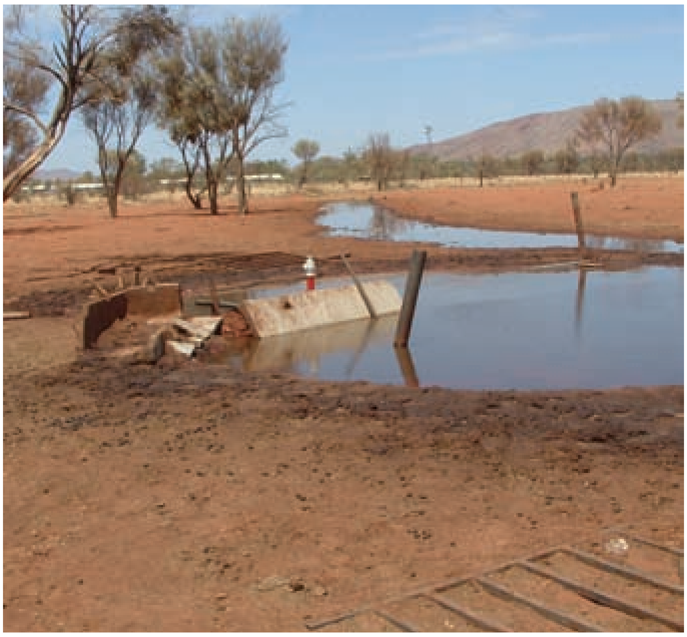


Camel damage to mulga trees in southern NT.

Photo, K. Schwartzkopff.

Dead camel in rockhole near Warburton, WA.

Photo, B. Zeng.



Camel damage to water infrastructure at Docker River, NT.

Photo, K. Schwartzkopff.